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# LM94021/LM94021Q

## Multi-Gain Analog Temperature Sensor

### General Description

The LM94021 is a precision analog output CMOS integrated-circuit temperature sensor that operates at a supply voltage as low as 1.5V. While operating over the wide temperature range of  $-50^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ , the LM94021 delivers an output voltage that is inversely proportional to measured temperature. The LM94021's low supply current makes it ideal for battery-powered systems as well as general temperature sensing applications.

Two logic inputs, Gain Select 1 (GS1) and Gain Select 0 (GS0), select the gain of the temperature-to-voltage output transfer function. Four slopes are selectable:  $-5.5\text{ mV}/^{\circ}\text{C}$ ,  $-8.2\text{ mV}/^{\circ}\text{C}$ ,  $-10.9\text{ mV}/^{\circ}\text{C}$ , and  $-13.6\text{ mV}/^{\circ}\text{C}$ . In the lowest gain configuration (GS1 and GS0 both tied low), the LM94021 can operate with a 1.5V supply while measuring temperature over the full  $-50^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$  operating range. Tying both inputs high causes the transfer function to have the largest gain of  $-13.6\text{ mV}/^{\circ}\text{C}$  for maximum temperature sensitivity. The gain-select inputs can be tied directly to  $V_{\text{DD}}$  or Ground without any pull-up or pull-down resistors, reducing component count and board area. These inputs can also be driven by logic signals allowing the system to optimize the gain during operation or system diagnostics.

### Applications

- Cell phones
- Wireless transceivers
- Battery management
- Automotive

- Disk drives
- Games
- Appliances

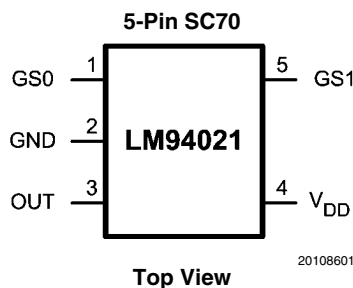
### Features

- LM94021Q is AEC-Q100 Grade 0 qualified and is manufactured on an Automotive grade Flow
- Low 1.5V operation
- Four selectable gains
- Very accurate over wide temperature range of  $-50^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$
- Low quiescent current
- Output is short-circuit protected
- Extremely small SC70 package
- Footprint compatible with the industry-standard LM20 temperature sensor
- UL Recognized Component 

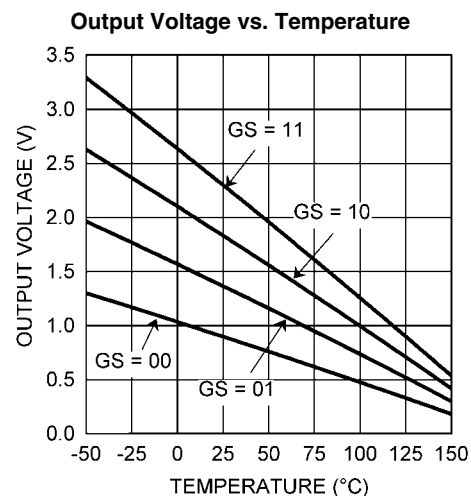
### Key Specifications

|                         |                                                                                                                                                                                                                                                                                                          |
|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ■ Supply Voltage        | 1.5V to 5.5V                                                                                                                                                                                                                                                                                             |
| ■ Supply Current        | 9 $\mu\text{A}$ (typ)                                                                                                                                                                                                                                                                                    |
| ■ Temperature Accuracy  | $20^{\circ}\text{C}$ to $40^{\circ}\text{C}$ $\pm 1.5^{\circ}\text{C}$<br>$-50^{\circ}\text{C}$ to $70^{\circ}\text{C}$ $\pm 1.8^{\circ}\text{C}$<br>$-50^{\circ}\text{C}$ to $90^{\circ}\text{C}$ $\pm 2.1^{\circ}\text{C}$<br>$-50^{\circ}\text{C}$ to $150^{\circ}\text{C}$ $\pm 2.7^{\circ}\text{C}$ |
| ■ Operating Temperature | $-50^{\circ}\text{C}$ to $150^{\circ}\text{C}$                                                                                                                                                                                                                                                           |

### Connection Diagram

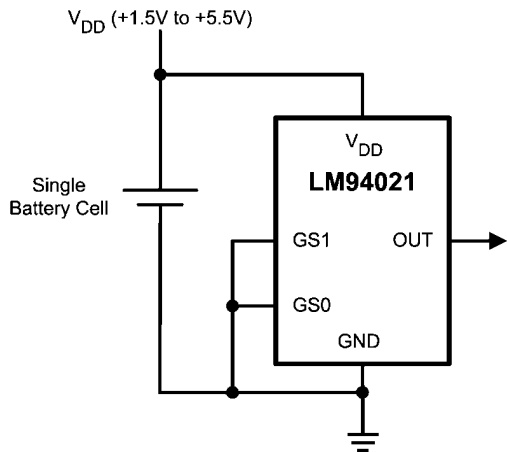


### Typical Transfer Characteristic



## Typical Application

Full-Range Celsius Temperature Sensor (–50°C to +150°C) operating from a Single Battery Cell



## Ordering Information

| Package    | Part Number   | Package Marking | Temperature Accuracy                                   | Transport Media        | NSC Drawing |
|------------|---------------|-----------------|--------------------------------------------------------|------------------------|-------------|
| 5-Pin SC70 | LM94021BIMG   | 21B             | $\pm 1.5^{\circ}\text{C}$ to $\pm 2.7^{\circ}\text{C}$ | 1k Units Tape and Reel | MAA05A      |
|            | LM94021BIMGX  |                 |                                                        | 3k Units Tape and Reel |             |
| 5-Pin SC70 | LM94021QBIMG  | 21Q             | $\pm 1.5^{\circ}\text{C}$ to $\pm 2.7^{\circ}\text{C}$ | 1k Units Tape and Reel | MAA05A      |
|            | LM94021QBIMGX |                 |                                                        | 3k Units Tape and Reel |             |

## Pin Descriptions

| Label           | Pin Number | Type          | Equivalent Circuit | Function                                                                         |
|-----------------|------------|---------------|--------------------|----------------------------------------------------------------------------------|
| GS1             | 5          | Logic Input   |                    | Gain Select 1 - One of two inputs for selecting the slope of the output response |
| GS0             | 1          | Logic Input   |                    | Gain Select 0 - One of two inputs for selecting the slope of the output response |
| OUT             | 3          | Analog Output |                    | Outputs a voltage which is inversely proportional to temperature                 |
| V <sub>DD</sub> | 4          | Power         |                    | Positive Supply Voltage                                                          |
| GND             | 2          | Ground        |                    | Power Supply Ground                                                              |

**Absolute Maximum Ratings** (Note 1)

|                                             |                              |
|---------------------------------------------|------------------------------|
| Supply Voltage                              | −0.3V to +6.0V               |
| Voltage at Output Pin                       | −0.3V to ( $V_{DD} + 0.5V$ ) |
| Output Current                              | ±7 mA                        |
| Voltage at GS0 and GS1 Input Pins           | −0.3V to +6.0V               |
| Input Current at any pin (Note 2)           | 5 mA                         |
| Storage Temperature                         | −65°C to +150°C              |
| Maximum Junction Temperature ( $T_{JMAX}$ ) | +150°C                       |
| ESD Susceptibility (Note 3)                 |                              |
| Human Body Model                            | 2500V                        |

Machine Model

250V

Soldering process must comply with National's Reflow Temperature Profile specifications. Refer to [www.national.com/packaging](http://www.national.com/packaging). (Note 4)

**Operating Ratings** (Note 1)

|                                               |                                 |
|-----------------------------------------------|---------------------------------|
| Specified Temperature Range                   | $T_{MIN} \leq T_A \leq T_{MAX}$ |
| LM94021                                       | −50°C $\leq T_A \leq$ +150°C    |
| Supply Voltage Range ( $V_{DD}$ )             | +1.5 V to +5.5 V                |
| Thermal Resistance ( $\theta_{JA}$ ) (Note 5) |                                 |
| 5-Pin SC70                                    | 415°C/W                         |

**Accuracy Characteristics**

These limits do not include DC load regulation. These stated accuracy limits are with reference to the values in the LM94021 Transfer Table.

| Parameter                     | Conditions         |                                                                              | Limits<br>(Note 7) | Units<br>(Limit) |
|-------------------------------|--------------------|------------------------------------------------------------------------------|--------------------|------------------|
| Temperature Error<br>(Note 8) | GS1 = 0<br>GS0 = 0 | $T_A = +20^\circ\text{C}$ to $+40^\circ\text{C}$ ; $V_{DD} = 1.5V$ to $5.5V$ | ±1.5               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+70^\circ\text{C}$ ; $V_{DD} = 1.5V$ to $5.5V$  | ±1.8               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+90^\circ\text{C}$ ; $V_{DD} = 1.5V$ to $5.5V$  | ±2.1               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+120^\circ\text{C}$ ; $V_{DD} = 1.5V$ to $5.5V$ | ±2.4               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+150^\circ\text{C}$ ; $V_{DD} = 1.5V$ to $5.5V$ | ±2.7               | °C (max)         |
|                               |                    | $T_A = -50^\circ\text{C}$ to $+0^\circ\text{C}$ ; $V_{DD} = 1.6V$ to $5.5V$  | ±1.8               | °C (max)         |
|                               | GS1 = 0<br>GS0 = 1 | $T_A = +20^\circ\text{C}$ to $+40^\circ\text{C}$ ; $V_{DD} = 1.8V$ to $5.5V$ | ±1.5               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+70^\circ\text{C}$ ; $V_{DD} = 1.9V$ to $5.5V$  | ±1.8               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+90^\circ\text{C}$ ; $V_{DD} = 1.9V$ to $5.5V$  | ±2.1               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+120^\circ\text{C}$ ; $V_{DD} = 1.9V$ to $5.5V$ | ±2.4               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+150^\circ\text{C}$ ; $V_{DD} = 1.9V$ to $5.5V$ | ±2.7               | °C (max)         |
|                               |                    | $T_A = -50^\circ\text{C}$ to $+0^\circ\text{C}$ ; $V_{DD} = 2.3V$ to $5.5V$  | ±1.8               | °C (max)         |
|                               | GS1 = 1<br>GS0 = 0 | $T_A = +20^\circ\text{C}$ to $+40^\circ\text{C}$ ; $V_{DD} = 2.2V$ to $5.5V$ | ±1.5               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+70^\circ\text{C}$ ; $V_{DD} = 2.4V$ to $5.5V$  | ±1.8               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+90^\circ\text{C}$ ; $V_{DD} = 2.4V$ to $5.5V$  | ±2.1               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+120^\circ\text{C}$ ; $V_{DD} = 2.4V$ to $5.5V$ | ±2.4               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+150^\circ\text{C}$ ; $V_{DD} = 2.4V$ to $5.5V$ | ±2.7               | °C (max)         |
|                               |                    | $T_A = -50^\circ\text{C}$ to $+0^\circ\text{C}$ ; $V_{DD} = 3.0V$ to $5.5V$  | ±1.8               | °C (max)         |
|                               | GS1 = 1<br>GS0 = 1 | $T_A = +20^\circ\text{C}$ to $+40^\circ\text{C}$ ; $V_{DD} = 2.7V$ to $5.5V$ | ±1.5               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+70^\circ\text{C}$ ; $V_{DD} = 3.0V$ to $5.5V$  | ±1.8               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+90^\circ\text{C}$ ; $V_{DD} = 3.0V$ to $5.5V$  | ±2.1               | °C (max)         |
|                               |                    | $T_A = +0^\circ\text{C}$ to $+120^\circ\text{C}$ ; $V_{DD} = 3.0V$ to $5.5V$ | ±2.4               | °C (max)         |
|                               |                    | $T_A = 0^\circ\text{C}$ to $+150^\circ\text{C}$ ; $V_{DD} = 3.0V$ to $5.5V$  | ±2.7               | °C (max)         |
|                               |                    | $T_A = -50^\circ\text{C}$ to $+0^\circ\text{C}$ ; $V_{DD} = 3.6V$ to $5.5V$  | ±1.8               | °C (max)         |

## Electrical Characteristics

Unless otherwise noted, these specifications apply for  $V_{DD} = +1.5V$  to  $+5.5V$ . **Boldface limits apply for  $T_A = T_J = T_{MIN}$  to  $T_{MAX}$** ; all other limits  $T_A = T_J = 25^\circ C$ .

| Symbol   | Parameter                                        | Conditions                                                                               | Typical<br>( <i>Note 6</i> )   | Limits<br>( <i>Note 7</i> ) | Units<br>(Limit)                 |
|----------|--------------------------------------------------|------------------------------------------------------------------------------------------|--------------------------------|-----------------------------|----------------------------------|
|          | Sensor Gain                                      | GS1 = 0, GS0 = 0<br>GS1 = 0, GS1 = 1<br>GS1 = 1, GS0 = 0<br>GS1 = 1, GS0 = 1             | –5.5<br>–8.2<br>–10.9<br>–13.6 |                             | mV/°C<br>mV/°C<br>mV/°C<br>mV/°C |
|          | Load Regulation<br>( <i>Note 10</i> )            | Source $\leq 2.0 \mu A$ ( <i>Note 11</i> )<br>Sink $\leq 100 \mu A$<br>Sink = $50 \mu A$ | 0.4                            | –1<br>1.6                   | mV (max)<br>mV (max)<br>mV       |
|          | Line Regulation ( <i>Note 14</i> )               | $(V_{DD} - V_{OUT}) \geq 200 mV$                                                         | 200                            |                             | $\mu V/V$                        |
| $I_S$    | Supply Current                                   | $T_A = +30^\circ C$ to $+150^\circ C$<br>$T_A = -50^\circ C$ to $+150^\circ C$           | 9                              | 12<br>13                    | $\mu A$ (max)<br>$\mu A$ (max)   |
| $C_L$    | Output Load Capacitance                          |                                                                                          | 1100                           |                             | pF (max)                         |
|          | Power-on Time<br>( <i>Note 12</i> )              | $C_L = 0 pF$<br>$C_L = 1100 pF$                                                          | 0.7<br>0.8                     | 1.6<br>2.4                  | ms (max)<br>ms (max)             |
| $V_{IH}$ | GS1 and GS0 Input Logic "1"<br>Threshold Voltage |                                                                                          |                                | $V_{DD} - 0.5V$             | V (min)                          |
| $V_{IL}$ | GS1 and GS0 Input Logic "0"<br>Threshold Voltage |                                                                                          |                                | 0.5                         | V (max)                          |
| $I_{IH}$ | Logic "1" Input Current<br>( <i>Note 13</i> )    |                                                                                          | 0.001                          | 1                           | $\mu A$ (max)                    |
| $I_{IL}$ | Logic "0" Input Current<br>( <i>Note 13</i> )    |                                                                                          | 0.001                          | 1                           | $\mu A$ (max)                    |

**Note 1:** *Absolute Maximum Ratings* indicate limits beyond which damage to the device may occur. *Operating Ratings* indicate conditions for which the device is functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the *Electrical Characteristics*. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.

**Note 2:** When the input voltage ( $V_I$ ) at any pin exceeds power supplies ( $V_I < GND$  or  $V_I > V^+$ ), the current at that pin should be limited to 5 mA.

**Note 3:** The human body model is a 100 pF capacitor discharged through a 1.5 k $\Omega$  resistor into each pin. The machine model is a 200 pF capacitor discharged directly into each pin.

**Note 4:** Reflow temperature profiles are different for lead-free and non-lead-free packages.

**Note 5:** The junction to ambient thermal resistance ( $\theta_{JA}$ ) is specified without a heat sink in still air.

**Note 6:** Typicals are at  $T_J = T_A = 25^\circ C$  and represent most likely parametric norm.

**Note 7:** Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

**Note 8:** Accuracy is defined as the error between the measured and reference output voltages, tabulated in the Transfer Table at the specified conditions of supply gain setting, voltage, and temperature (expressed in  $^\circ C$ ). Accuracy limits include line regulation within the specified conditions. Accuracy limits do not include load regulation; they assume no DC load.

**Note 9:** Changes in output due to self heating can be computed by multiplying the internal dissipation by the thermal resistance.

**Note 10:** Source currents are flowing out of the LM94021. Sink currents are flowing into the LM94021.

**Note 11:** Assumes  $(V_{DD} - V_{OUT}) \geq 200 mV$ .

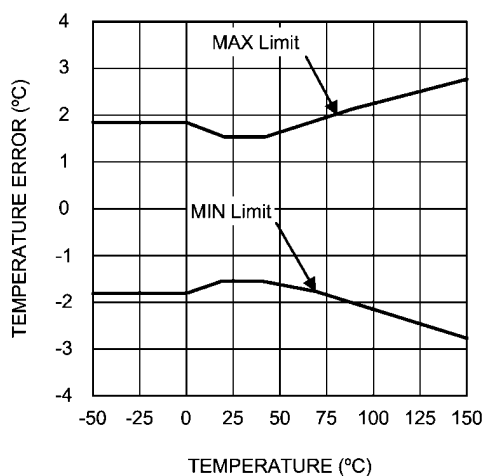
**Note 12:** Guaranteed by design.

**Note 13:** The input current is leakage only and is highest at high temperature. It is typically only 0.001  $\mu A$ . The 1  $\mu A$  limit is solely based on a testing limitation and does not reflect the actual performance of the part.

**Note 14:** Line regulation is calculated by subtracting the output voltage at the highest supply voltage from the output voltage at the lowest supply voltage. The typical line regulation specification does not include the output voltage shift discussed in Section 5.0.

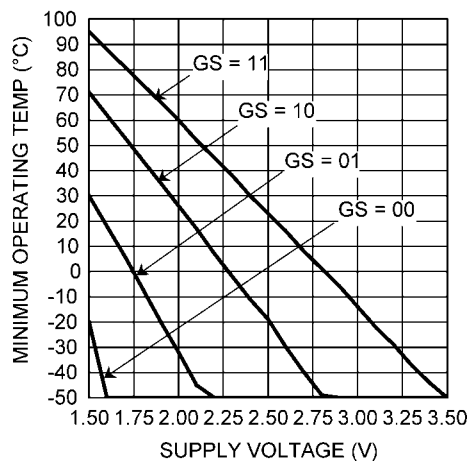
## Typical Performance Characteristics

### Temperature Error vs. Temperature



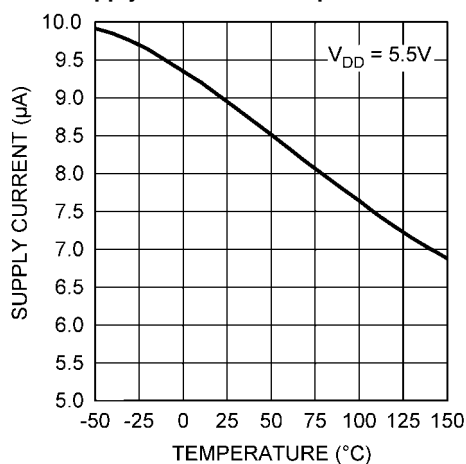
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### Minimum Operating Temperature vs. Supply Voltage



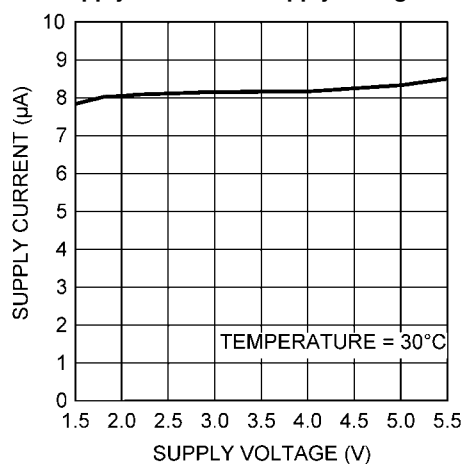
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### Supply Current vs. Temperature



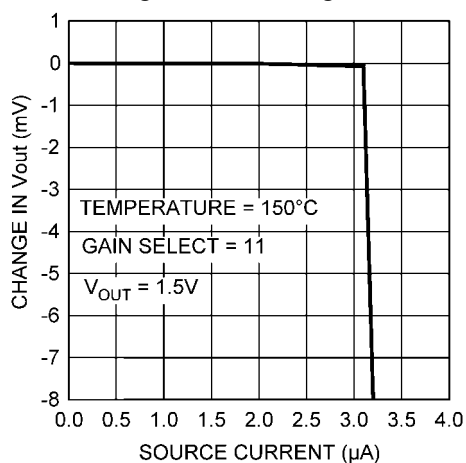
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### Supply Current vs. Supply Voltage



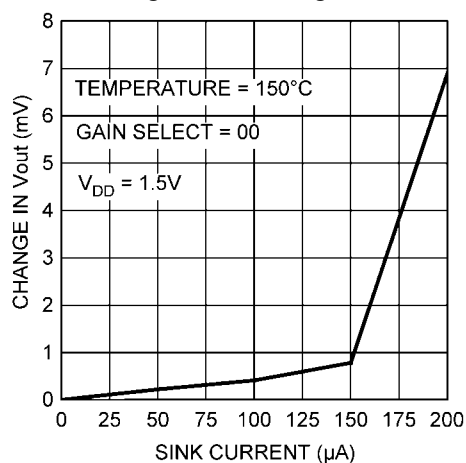
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### Load Regulation, Sourcing Current

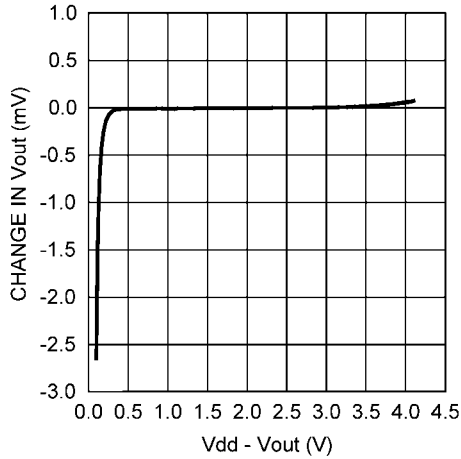


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### Load Regulation, Sinking Current

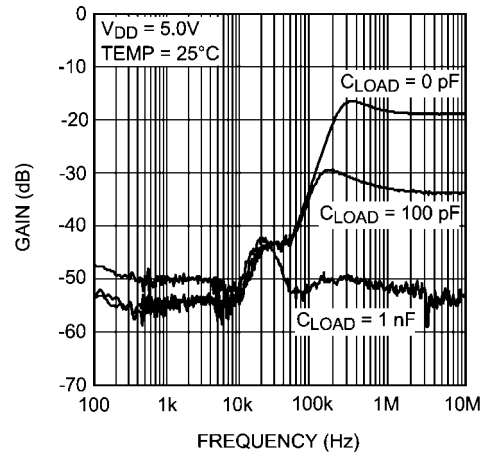


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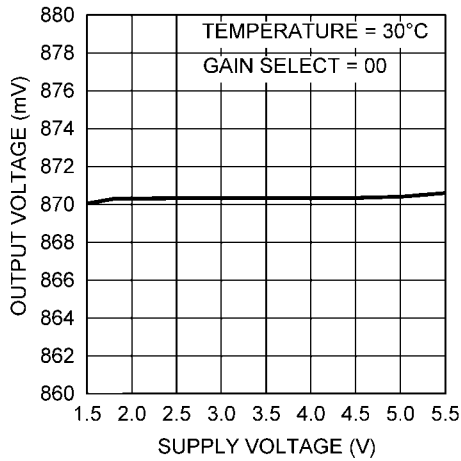
Change in  $V_{OUT}$  vs. Overhead Voltage

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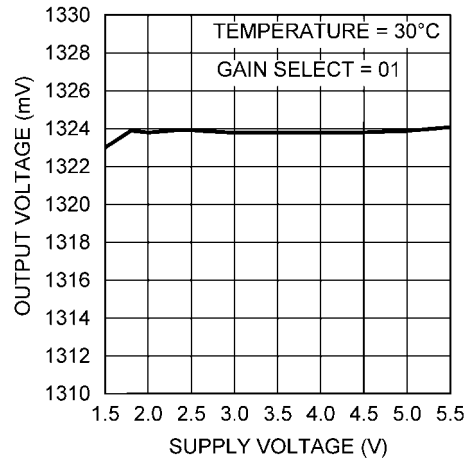
Supply Noise Gain vs. Frequency



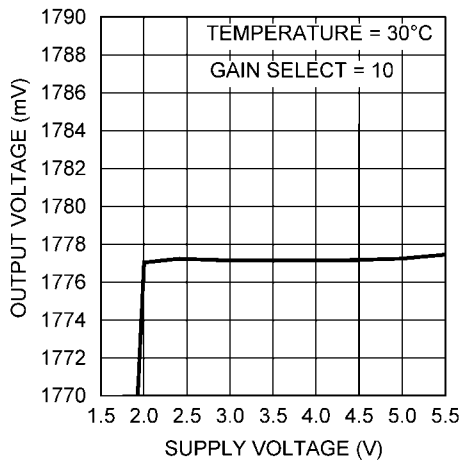
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Line Regulation: Output Voltage vs. Supply Voltage  
Gain Select = 00

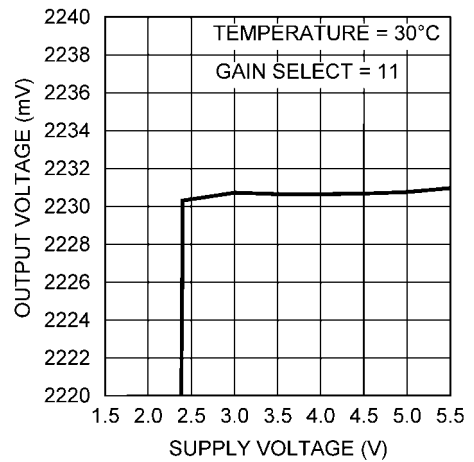
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Line Regulation: Output Voltage vs. Supply Voltage  
Gain Select = 01

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Line Regulation: Output Voltage vs. Supply Voltage  
Gain Select = 10

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Line Regulation: Output Voltage vs. Supply Voltage  
Gain Select = 11

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## Application Information

### 1.0 LM94021 TRANSFER FUNCTION

The LM94021 has four selectable gains, each of which can be selected by the GS1 and GS0 input pins. The output voltage for each gain, across the complete operating temperature range is shown in the LM94021 Transfer Table, below. This table is the reference from which the LM94021 accuracy specifications (listed in the Electrical Characteristics section) are determined. This table can be used, for example, in a host processor look-up table. A file containing this data is available for download at [www.national.com/appinfo/tempsensors](http://www.national.com/appinfo/tempsensors).

**LM94021 Transfer Table**

The output voltages in this table apply for  $V_{DD} = 5V$ .

| Temperature (°C) | GS = 00 (mV) | GS = 01 (mV) | GS = 10 (mV) | GS = 11 (mV) |
|------------------|--------------|--------------|--------------|--------------|
| -50              | 1299         | 1955         | 2616         | 3277         |
| -49              | 1294         | 1949         | 2607         | 3266         |
| -48              | 1289         | 1942         | 2598         | 3254         |
| -47              | 1284         | 1935         | 2589         | 3243         |
| -46              | 1278         | 1928         | 2580         | 3232         |
| -45              | 1273         | 1921         | 2571         | 3221         |
| -44              | 1268         | 1915         | 2562         | 3210         |
| -43              | 1263         | 1908         | 2553         | 3199         |
| -42              | 1257         | 1900         | 2543         | 3186         |
| -41              | 1252         | 1892         | 2533         | 3173         |
| -40              | 1247         | 1885         | 2522         | 3160         |
| -39              | 1242         | 1877         | 2512         | 3147         |
| -38              | 1236         | 1869         | 2501         | 3134         |
| -37              | 1231         | 1861         | 2491         | 3121         |
| -36              | 1226         | 1853         | 2481         | 3108         |
| -35              | 1221         | 1845         | 2470         | 3095         |
| -34              | 1215         | 1838         | 2460         | 3082         |
| -33              | 1210         | 1830         | 2449         | 3069         |
| -32              | 1205         | 1822         | 2439         | 3056         |
| -31              | 1200         | 1814         | 2429         | 3043         |
| -30              | 1194         | 1806         | 2418         | 3030         |
| -29              | 1189         | 1798         | 2408         | 3017         |
| -28              | 1184         | 1790         | 2397         | 3004         |
| -27              | 1178         | 1783         | 2387         | 2991         |
| -26              | 1173         | 1775         | 2376         | 2978         |
| -25              | 1168         | 1767         | 2366         | 2965         |
| -24              | 1162         | 1759         | 2355         | 2952         |
| -23              | 1157         | 1751         | 2345         | 2938         |
| -22              | 1152         | 1743         | 2334         | 2925         |
| -21              | 1146         | 1735         | 2324         | 2912         |
| -20              | 1141         | 1727         | 2313         | 2899         |
| -19              | 1136         | 1719         | 2302         | 2886         |
| -18              | 1130         | 1711         | 2292         | 2873         |
| -17              | 1125         | 1703         | 2281         | 2859         |
| -16              | 1120         | 1695         | 2271         | 2846         |
| -15              | 1114         | 1687         | 2260         | 2833         |

| Temperature (°C) | GS = 00 (mV) | GS = 01 (mV) | GS = 10 (mV) | GS = 11 (mV) |
|------------------|--------------|--------------|--------------|--------------|
| -14              | 1109         | 1679         | 2250         | 2820         |
| -13              | 1104         | 1671         | 2239         | 2807         |
| -12              | 1098         | 1663         | 2228         | 2793         |
| -11              | 1093         | 1656         | 2218         | 2780         |
| -10              | 1088         | 1648         | 2207         | 2767         |
| -9               | 1082         | 1639         | 2197         | 2754         |
| -8               | 1077         | 1631         | 2186         | 2740         |
| -7               | 1072         | 1623         | 2175         | 2727         |
| -6               | 1066         | 1615         | 2164         | 2714         |
| -5               | 1061         | 1607         | 2154         | 2700         |
| -4               | 1055         | 1599         | 2143         | 2687         |
| -3               | 1050         | 1591         | 2132         | 2674         |
| -2               | 1044         | 1583         | 2122         | 2660         |
| -1               | 1039         | 1575         | 2111         | 2647         |
| 0                | 1034         | 1567         | 2100         | 2633         |
| 1                | 1028         | 1559         | 2089         | 2620         |
| 2                | 1023         | 1551         | 2079         | 2607         |
| 3                | 1017         | 1543         | 2068         | 2593         |
| 4                | 1012         | 1535         | 2057         | 2580         |
| 5                | 1007         | 1527         | 2047         | 2567         |
| 6                | 1001         | 1519         | 2036         | 2553         |
| 7                | 996          | 1511         | 2025         | 2540         |
| 8                | 990          | 1502         | 2014         | 2527         |
| 9                | 985          | 1494         | 2004         | 2513         |
| 10               | 980          | 1486         | 1993         | 2500         |
| 11               | 974          | 1478         | 1982         | 2486         |
| 12               | 969          | 1470         | 1971         | 2473         |
| 13               | 963          | 1462         | 1961         | 2459         |
| 14               | 958          | 1454         | 1950         | 2446         |
| 15               | 952          | 1446         | 1939         | 2433         |
| 16               | 947          | 1438         | 1928         | 2419         |
| 17               | 941          | 1430         | 1918         | 2406         |
| 18               | 936          | 1421         | 1907         | 2392         |
| 19               | 931          | 1413         | 1896         | 2379         |
| 20               | 925          | 1405         | 1885         | 2365         |
| 21               | 920          | 1397         | 1874         | 2352         |
| 22               | 914          | 1389         | 1864         | 2338         |
| 23               | 909          | 1381         | 1853         | 2325         |
| 24               | 903          | 1373         | 1842         | 2311         |
| 25               | 898          | 1365         | 1831         | 2298         |
| 26               | 892          | 1356         | 1820         | 2285         |
| 27               | 887          | 1348         | 1810         | 2271         |
| 28               | 882          | 1340         | 1799         | 2258         |
| 29               | 876          | 1332         | 1788         | 2244         |
| 30               | 871          | 1324         | 1777         | 2231         |
| 31               | 865          | 1316         | 1766         | 2217         |
| 32               | 860          | 1308         | 1756         | 2204         |
| 33               | 854          | 1299         | 1745         | 2190         |



| Temperature<br>(°C) | GS = 00<br>(mV) | GS = 01<br>(mV) | GS = 10<br>(mV) | GS = 11<br>(mV) |
|---------------------|-----------------|-----------------|-----------------|-----------------|
| 34                  | 849             | 1291            | 1734            | 2176            |
| 35                  | 843             | 1283            | 1723            | 2163            |
| 36                  | 838             | 1275            | 1712            | 2149            |
| 37                  | 832             | 1267            | 1701            | 2136            |
| 38                  | 827             | 1258            | 1690            | 2122            |
| 39                  | 821             | 1250            | 1679            | 2108            |
| 40                  | 816             | 1242            | 1668            | 2095            |
| 41                  | 810             | 1234            | 1657            | 2081            |
| 42                  | 804             | 1225            | 1646            | 2067            |
| 43                  | 799             | 1217            | 1635            | 2054            |
| 44                  | 793             | 1209            | 1624            | 2040            |
| 45                  | 788             | 1201            | 1613            | 2026            |
| 46                  | 782             | 1192            | 1602            | 2012            |
| 47                  | 777             | 1184            | 1591            | 1999            |
| 48                  | 771             | 1176            | 1580            | 1985            |
| 49                  | 766             | 1167            | 1569            | 1971            |
| 50                  | 760             | 1159            | 1558            | 1958            |
| 51                  | 754             | 1151            | 1547            | 1944            |
| 52                  | 749             | 1143            | 1536            | 1930            |
| 53                  | 743             | 1134            | 1525            | 1916            |
| 54                  | 738             | 1126            | 1514            | 1902            |
| 55                  | 732             | 1118            | 1503            | 1888            |
| 56                  | 726             | 1109            | 1492            | 1875            |
| 57                  | 721             | 1101            | 1481            | 1861            |
| 58                  | 715             | 1093            | 1470            | 1847            |
| 59                  | 710             | 1084            | 1459            | 1833            |
| 60                  | 704             | 1076            | 1448            | 1819            |
| 61                  | 698             | 1067            | 1436            | 1805            |
| 62                  | 693             | 1059            | 1425            | 1791            |
| 63                  | 687             | 1051            | 1414            | 1777            |
| 64                  | 681             | 1042            | 1403            | 1763            |
| 65                  | 676             | 1034            | 1391            | 1749            |
| 66                  | 670             | 1025            | 1380            | 1735            |
| 67                  | 664             | 1017            | 1369            | 1721            |
| 68                  | 659             | 1008            | 1358            | 1707            |
| 69                  | 653             | 1000            | 1346            | 1693            |
| 70                  | 647             | 991             | 1335            | 1679            |
| 71                  | 642             | 983             | 1324            | 1665            |
| 72                  | 636             | 974             | 1313            | 1651            |
| 73                  | 630             | 966             | 1301            | 1637            |
| 74                  | 625             | 957             | 1290            | 1623            |
| 75                  | 619             | 949             | 1279            | 1609            |
| 76                  | 613             | 941             | 1268            | 1595            |
| 77                  | 608             | 932             | 1257            | 1581            |
| 78                  | 602             | 924             | 1245            | 1567            |
| 79                  | 596             | 915             | 1234            | 1553            |
| 80                  | 591             | 907             | 1223            | 1539            |
| 81                  | 585             | 898             | 1212            | 1525            |

| Temperature<br>(°C) | GS = 00<br>(mV) | GS = 01<br>(mV) | GS = 10<br>(mV) | GS = 11<br>(mV) |
|---------------------|-----------------|-----------------|-----------------|-----------------|
| 82                  | 579             | 890             | 1201            | 1511            |
| 83                  | 574             | 881             | 1189            | 1497            |
| 84                  | 568             | 873             | 1178            | 1483            |
| 85                  | 562             | 865             | 1167            | 1469            |
| 86                  | 557             | 856             | 1155            | 1455            |
| 87                  | 551             | 848             | 1144            | 1441            |
| 88                  | 545             | 839             | 1133            | 1427            |
| 89                  | 539             | 831             | 1122            | 1413            |
| 90                  | 534             | 822             | 1110            | 1399            |
| 91                  | 528             | 814             | 1099            | 1385            |
| 92                  | 522             | 805             | 1088            | 1371            |
| 93                  | 517             | 797             | 1076            | 1356            |
| 94                  | 511             | 788             | 1065            | 1342            |
| 95                  | 505             | 779             | 1054            | 1328            |
| 96                  | 499             | 771             | 1042            | 1314            |
| 97                  | 494             | 762             | 1031            | 1300            |
| 98                  | 488             | 754             | 1020            | 1286            |
| 99                  | 482             | 745             | 1008            | 1272            |
| 100                 | 476             | 737             | 997             | 1257            |
| 101                 | 471             | 728             | 986             | 1243            |
| 102                 | 465             | 720             | 974             | 1229            |
| 103                 | 459             | 711             | 963             | 1215            |
| 104                 | 453             | 702             | 951             | 1201            |
| 105                 | 448             | 694             | 940             | 1186            |
| 106                 | 442             | 685             | 929             | 1172            |
| 107                 | 436             | 677             | 917             | 1158            |
| 108                 | 430             | 668             | 906             | 1144            |
| 109                 | 425             | 660             | 895             | 1130            |
| 110                 | 419             | 651             | 883             | 1115            |
| 111                 | 413             | 642             | 872             | 1101            |
| 112                 | 407             | 634             | 860             | 1087            |
| 113                 | 401             | 625             | 849             | 1073            |
| 114                 | 396             | 617             | 837             | 1058            |
| 115                 | 390             | 608             | 826             | 1044            |
| 116                 | 384             | 599             | 814             | 1030            |
| 117                 | 378             | 591             | 803             | 1015            |
| 118                 | 372             | 582             | 791             | 1001            |
| 119                 | 367             | 573             | 780             | 987             |
| 120                 | 361             | 565             | 769             | 973             |
| 121                 | 355             | 556             | 757             | 958             |
| 122                 | 349             | 547             | 745             | 944             |
| 123                 | 343             | 539             | 734             | 929             |
| 124                 | 337             | 530             | 722             | 915             |
| 125                 | 332             | 521             | 711             | 901             |
| 126                 | 326             | 513             | 699             | 886             |
| 127                 | 320             | 504             | 688             | 872             |
| 128                 | 314             | 495             | 676             | 858             |
| 129                 | 308             | 487             | 665             | 843             |

| Temperature (°C) | GS = 00 (mV) | GS = 01 (mV) | GS = 10 (mV) | GS = 11 (mV) |
|------------------|--------------|--------------|--------------|--------------|
| 130              | 302          | 478          | 653          | 829          |
| 131              | 296          | 469          | 642          | 814          |
| 132              | 291          | 460          | 630          | 800          |
| 133              | 285          | 452          | 618          | 786          |
| 134              | 279          | 443          | 607          | 771          |
| 135              | 273          | 434          | 595          | 757          |
| 136              | 267          | 425          | 584          | 742          |
| 137              | 261          | 416          | 572          | 728          |
| 138              | 255          | 408          | 560          | 713          |
| 139              | 249          | 399          | 549          | 699          |
| 140              | 243          | 390          | 537          | 684          |
| 141              | 237          | 381          | 525          | 670          |
| 142              | 231          | 372          | 514          | 655          |
| 143              | 225          | 363          | 502          | 640          |
| 144              | 219          | 354          | 490          | 626          |
| 145              | 213          | 346          | 479          | 611          |
| 146              | 207          | 337          | 467          | 597          |
| 147              | 201          | 328          | 455          | 582          |
| 148              | 195          | 319          | 443          | 568          |
| 149              | 189          | 310          | 432          | 553          |
| 150              | 183          | 301          | 420          | 538          |

Although the LM94021 is very linear, its response does have a slight downward parabolic shape. This shape is very accurately reflected in the LM94021 Transfer Table. For a linear approximation, a line can easily be calculated over the desired temperature range from the Table using the two-point equation:

$$V - V_1 = \left( \frac{V_2 - V_1}{T_2 - T_1} \right) \times (T - T_1)$$

Where V is in mV, T is in °C, T<sub>1</sub> and V<sub>1</sub> are the coordinates of the lowest temperature, T<sub>2</sub> and V<sub>2</sub> are the coordinates of the highest temperature.

For example, if we want to determine the equation of a line with the Gain Setting at GS1 = 0 and GS0 = 0, over a temperature range of 20°C to 50°C, we would proceed as follows:

$$V - 925 \text{ mV} = \left( \frac{760 \text{ mV} - 925 \text{ mV}}{50^\circ\text{C} - 20^\circ\text{C}} \right) \times (T - 20^\circ\text{C})$$

$$V - 925 \text{ mV} = (-5.50 \text{ mV} / ^\circ\text{C}) \times (T - 20^\circ\text{C})$$

$$V = (-5.50 \text{ mV} / ^\circ\text{C}) \times T + 1035 \text{ mV}$$

Using this method of linear approximation, the transfer function can be approximated for one or more temperature ranges of interest.

## 2.0 MOUNTING AND THERMAL CONDUCTIVITY

The LM94021 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface.

To ensure good thermal conductivity, the backside of the LM94021 die is directly attached to the GND pin (Pin 2). The temperatures of the lands and traces to the other leads of the LM94021 will also affect the temperature reading.

Alternatively, the LM94021 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM94021 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. If moisture creates a short circuit from the output to ground or V<sub>DD</sub>, the output from the LM94021 will not be correct. Printed-circuit coatings are often used to ensure that moisture cannot corrode the leads or circuit traces.

The thermal resistance junction to ambient (θ<sub>JA</sub>) is the parameter used to calculate the rise of a device junction temperature due to its power dissipation. The equation used to calculate the rise in the LM94021's die temperature is

$$T_J = T_A + \theta_{JA} [(V_{DD} I_Q) + (V_{DD} - V_O) I_L]$$

where T<sub>A</sub> is the ambient temperature, I<sub>Q</sub> is the quiescent current, I<sub>L</sub> is the load current on the output, and V<sub>O</sub> is the output voltage. For example, in an application where T<sub>A</sub> = 30°C, V<sub>DD</sub> = 5 V, I<sub>DD</sub> = 9 μA, Gain Select = 11, V<sub>OUT</sub> = 2.231 mV, and I<sub>L</sub> = 2 μA, the junction temperature would be 30.021°C, showing a self-heating error of only 0.021°C. Since the LM94021's junction temperature is the actual temperature being measured, care should be taken to minimize the load current that the LM94021 is required to drive. Figure 1 shows the thermal resistance of the LM94021.

| Device Number | NS Package Number | Thermal Resistance (θ <sub>JA</sub> ) |
|---------------|-------------------|---------------------------------------|
| LM94021BIMG   | MAA05A            | 415°C/W                               |

FIGURE 1. LM94021 Thermal Resistance

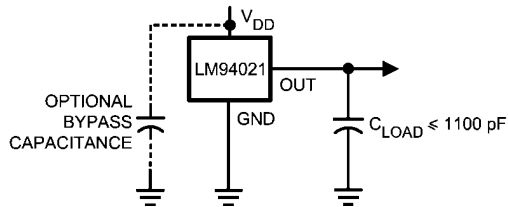
## 3.0 NOISE CONSIDERATIONS

The LM94021 has excellent noise rejection (the ratio of the AC signal on V<sub>OUT</sub> to the AC signal on V<sub>DD</sub>). During bench tests, sine wave rejection of -54 dB or better was observed over 200 Hz to 10 kHz; Also, -28 dB or better was observed from 10 kHz to 1 MHz. A load capacitor on the output can help filter noise; for example, a 1 nF load capacitor resulted in -51 dB or better from 200 Hz to 1 MHz.

There is no specific requirement for the use of a bypass capacitor close to the LM94021 because it does not draw transient currents. For operation in very noisy environments, some bypass capacitance may be required. The capacitance does not need to be in close proximity to the LM94021. The LM94021 has been bench tested successfully with a bypass capacitor as far as 6 inches away. In fact, it can be powered by a properly-bypassed logic gate.

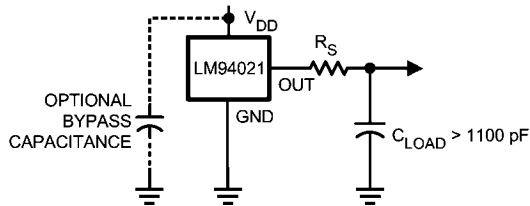
#### 4.0 CAPACITIVE LOADS

The LM94021 handles capacitive loading well. In an extremely noisy environment, or when driving a switched sampling input on an ADC, it may be necessary to add some filtering to minimize noise coupling. Without any precautions, the LM94021 can drive a capacitive load less than or equal to 1100 pF as shown in [Figure 2](#). For capacitive loads greater than 1100 pF, a series resistor may be required on the output, as shown in [Figure 3](#).



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**FIGURE 2. LM94021 No Decoupling Required for Capacitive Loads Less than 1100 pF**



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| $C_{LOAD}$       | $R_S$          |
|------------------|----------------|
| 1.1 nF to 99 nF  | 3 k $\Omega$   |
| 100 nF to 999 nF | 1.5 k $\Omega$ |
| 1 $\mu$ F        | 800 $\Omega$   |

**FIGURE 3. LM94021 with Series Resistor for Capacitive Loading greater than 1100 pF**

#### 5.0 OUTPUT VOLTAGE SHIFT

The LM94021 is very linear over temperature and supply voltage range. Due to the intrinsic behavior of an NMOS/PMOS rail-to-rail buffer, a slight shift in the output can occur when the supply voltage is ramped over the operating range of the device. The location of the shift is determined by the relative levels of  $V_{DD}$  and  $V_{OUT}$ . The shift typically occurs when  $V_{DD} - V_{OUT} = 1.0V$ .

This slight shift (a few millivolts) takes place over a wide change (approximately 200 mV) in  $V_{DD}$  or  $V_{OUT}$ . Since the shift takes place over a wide temperature change of 5°C to 20°C,  $V_{OUT}$  is always monotonic. The accuracy specifications in the Electrical Characteristics table already include this possible shift.

#### 6.0 SELECTABLE GAIN FOR OPTIMIZATION AND IN SITU TESTING

The Gain Select digital inputs can be tied to the rails or can be driven from digital outputs such as microcontroller GPIO pins. In low-supply voltage applications, the ability to reduce the gain to  $-5.5 \text{ mV}/^\circ\text{C}$  allows the LM94021 to operate over the full  $-50^\circ\text{C}$  to  $150^\circ\text{C}$  range. When a larger supply voltage is present, the gain can be increased as high as  $-13.6 \text{ mV}/^\circ\text{C}$ . The larger gain is optimal for reducing the effects of noise (for example, noise coupling on the output line or quantization noise induced by an analog-to-digital converter which may be sampling the LM94021 output).

Another application advantage of the digitally selectable gain is the ability to perform dynamic testing of the LM94021 while it is running in a system. By toggling the logic levels of the gain select pins and monitoring the resultant change in the output voltage level, the host system can verify the functionality of the LM94021.

## 7.0 APPLICATION CIRCUITS

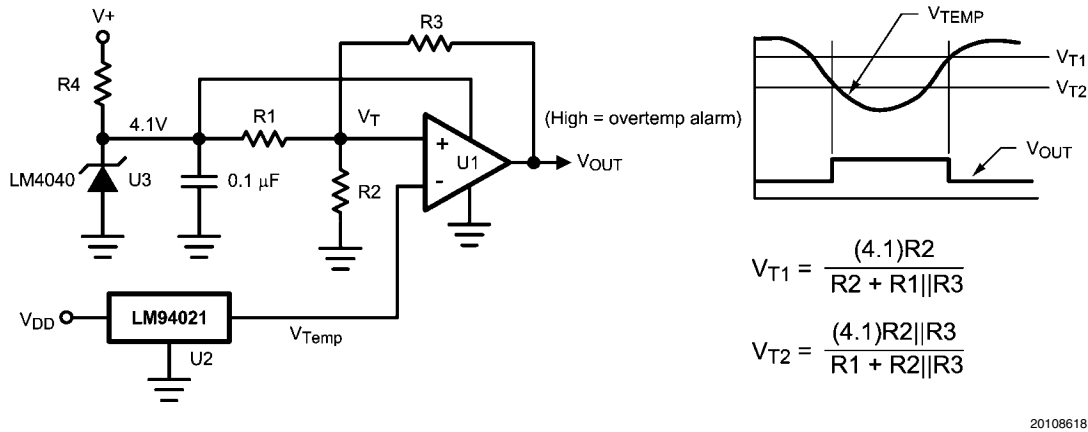


FIGURE 4. Celsius Thermostat

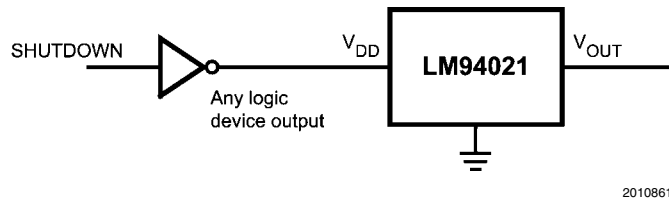
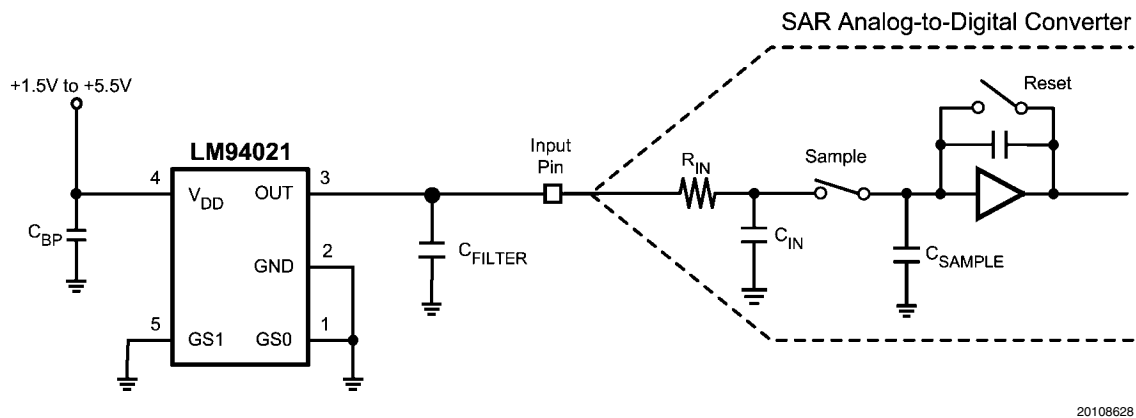


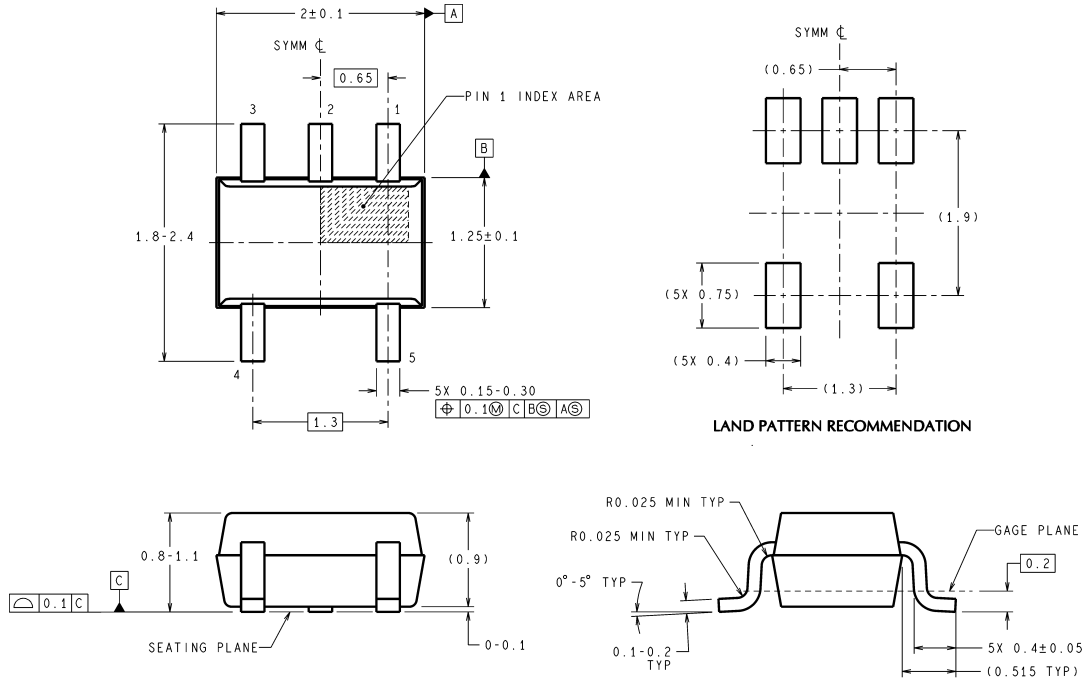
FIGURE 5. Conserving Power Dissipation with Shutdown



Most CMOS ADCs found in microcontrollers and ASICs have a sampled data comparator input structure. When the ADC charges the sampling cap, it requires instantaneous charge from the output of the analog source such as the LM94021 temperature sensor and many op amps. This requirement is easily accommodated by the addition of a capacitor ( $C_{\text{FILTER}}$ ). The size of  $C_{\text{FILTER}}$  depends on the size of the sampling capacitor and the sampling frequency. Since not all ADCs have identical input stages, the charge requirements will vary. This general ADC application is shown as an example only.

FIGURE 6. Suggested Connection to a Sampling Analog-to-Digital Converter Input Stage

# Physical Dimensions inches (millimeters) unless otherwise noted



DIMENSIONS ARE IN MILLIMETERS  
DIMENSIONS IN ( ) FOR REFERENCE ONLY

**5-Pin SC70**  
**NS Package Number MAA05A**

MAA05A (Rev D)

## Notes

## Notes

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| LVDS                           | <a href="http://www.national.com/lvds">www.national.com/lvds</a>               | Packaging                    | <a href="http://www.national.com/packaging">www.national.com/packaging</a>         |
| Power Management               | <a href="http://www.national.com/power">www.national.com/power</a>             | Green Compliance             | <a href="http://www.national.com/quality/green">www.national.com/quality/green</a> |
| Switching Regulators           | <a href="http://www.national.com/switchers">www.national.com/switchers</a>     | Distributors                 | <a href="http://www.national.com/contacts">www.national.com/contacts</a>           |
| LDOs                           | <a href="http://www.national.com/ldo">www.national.com/ldo</a>                 | Quality and Reliability      | <a href="http://www.national.com/quality">www.national.com/quality</a>             |
| LED Lighting                   | <a href="http://www.national.com/led">www.national.com/led</a>                 | Feedback/Support             | <a href="http://www.national.com/feedback">www.national.com/feedback</a>           |
| Voltage References             | <a href="http://www.national.com/vref">www.national.com/vref</a>               | Design Made Easy             | <a href="http://www.national.com/easy">www.national.com/easy</a>                   |
| PowerWise® Solutions           | <a href="http://www.national.com/powerwise">www.national.com/powerwise</a>     | Applications & Markets       | <a href="http://www.national.com/solutions">www.national.com/solutions</a>         |
| Serial Digital Interface (SDI) | <a href="http://www.national.com/sdi">www.national.com/sdi</a>                 | Mil/Aero                     | <a href="http://www.national.com/milaero">www.national.com/milaero</a>             |
| Temperature Sensors            | <a href="http://www.national.com/tempsensors">www.national.com/tempsensors</a> | SolarMagic™                  | <a href="http://www.national.com/solarmagic">www.national.com/solarmagic</a>       |
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